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APPLICATION FOR

UNITED STATES LETTERS PATENT

FOR

IMPROVED BANDWIDTH WIRELINE DATA TRANSMISSION SYSTEM AND METHOD

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BACKGROUND OF THE INVENTION

1. Related Application

This application is related to a U.S. provisional application titled "Improved Bandwidth Wireline Data Transmission System and Method" filed on March 30, 2000, serial number 60/193,098, and from which priority is hereby claimed for the present application.

2. Field of the Invention

This invention pertains to data communications and particularly to data communications on a wireline such as one employed in an oil or gas well borehole application.

3. Description of the Prior Art

It is common in an oil or gas well borehole application to transmit and receive electrical digital data and control signals between surface electronics and downhole electronics package via a wireline of one or more conductors connecting the two. Such signals are typically used to remotely control the functions of various downhole devices such as sensors for

detecting borehole parameters as well as tools and devices for performing functional operations in the borehole such as setting equipment or operating testers, motors, directional drilling equipment or the like, which may be operable in stages and in any event requiring a plurality of differing control signals at different times. Likewise, it is desirable to transmit information indicative of the operation of the downhole devices or parameters detected or measured downhole, to the surface over the same conductor path. It is customary in such downhole operations to utilize a sheathed or armored cable which includes either a single conductor or multiple conductors. A single conductor armored cable typically includes a single insulated conductor as a core, and a protective conductive sheathing surrounds the insulated core. The core and sheathing form an electrical circuit path for transmitting electrical power and data. The standard multi-conductor armored cable is a 7-conductor armored cable used for multiple channel tools. Such so called single conductor wireline cables, or similarly constructed multi-conductor cables, are almost exclusively used to operate downhole electrical devices because of a variety of reasons associated with the space limited and rigorous environment of a borehole. In such oil and gas borehole operations, a borehole depth of many thousands of feet is not uncommon. In communicating between the surface and downhole in a borehole over a wireline cable, control signals and data signals are normally converted to digital signals transmitted by a transmitter at rates up

to a maximum of 20 Kbits/second. A receiver on the other end of the cable receives the signals, and a processor decodes the signals for further use.

The transmission and receiver scheme described above operates well when the rate of transmission does not exceed about 20 Kbits/second or the wireline is relatively short. However, the wireline transmission medium does cause a problem when the transmission is over a relatively long length or as the data rate increases. That is, the detection and distinguishing of the two voltage levels associated with the digital signal is impaired by distortions caused by the medium. Distortions become more acute for faster bit rates, where the periods at each of the two voltage levels are very short. For example, the frequency characteristic of a typical single conductor wireline used for downhole application has a loss of about -20 db at 5.6 Khz for a 30,000 foot length. At higher frequencies, the loss is significantly greater.

Often, multi-conductor cables are used when multiple channels to several sensors are used. The most commonly used cable today is a 7-conductor armored logging cable. For comparison purposes, a cable of at least 30,000 feet in length wherein the cable is a 7-conductor cable provided within an armored logging cable having a nominal size of 7/16 inches has a frequency bandwidth of 90 to 270 Khz. Bandwidth is defined

as the frequency at which an input signal is attenuated to the point where the signal cannot be effectively recovered by the receiving device. Typically, and for the purposes of this disclosure, the attenuation is -60 db.

Today, while the wells become deeper, the measuring devices have also become more complex. That is, they provide data at a much greater rate. Moreover, the advent of digital computers installed at the well head measuring equipment have enabled the handling of greater volumes of data in a more effective fashion. All of this has occurred simultaneously increasing the requirements on the logging cable. The cables have become more complex i.e., they have added conductors, and the band pass requirements for the conductors have been increased. Still, the cables used today are unable to provide bandwidth in deep wells matching the transmission capabilities of the instrumentation.

There are several factors affecting the bandwidth of a particular cable configuration including resistance (R), capacitance (C), inductance (L) and conductance (or leakage.) Typically gains to be achieved in inductance and conductance are small since these factors are negligible. The most straightforward correction for high resistance of a cable, which is proportional to the diameter cable conductors, is to have larger diameter cables. This correction is opposed by the need to balance cable size with

borehole parameters. Parameters such as borehole diameter and fluid pressure lead designers to smaller diameter cables. Capacitance of logging cables has been minimized, thereby increasing bandwidth, by adding conductors or by using a coaxial cable. As discussed earlier, the coaxial cable is used by referencing a signal to the shield (or armor.) Although capacitance is improved, the capacitances of typical coaxial and multi-conductor cables are still around 40 to 60 pF/ft.

To address some of the deficiencies described above, the present invention provides a load bearing cable having improved bandwidth and lower capacitance per foot for use in wireline applications. This invention also provides a multi-conductor load bearing cable used in a single conductor mode with lower capacitance than the typical single conductor cable used today.

Although increasing the bandwidth of a cable is necessary to improve data rate transmission, it should also be appreciated that the efficient use of the bandwidth is also required. As discussed earlier, instruments now have the capability to transmit data at rates far beyond cable capabilities. Methods of encoding data for transmission used in the telecommunication industry include Quadrature Amplitude Modulation (QAM), Carrierless Amplitude and Phase (CAP) modulation, and Discrete

Multi-Tones (DMT) modulation. CAP is a modified QAM method, and DMT is the method in digital subscriber line (DSL) applications currently marketed mainly as an enhancement to internet connections. At this time, the well logging community has not taken advantage of the state of the art encoding methods. The primary driver being that the cables in current use cannot provide the bandwidth necessary to utilize these encoding methods efficiently.

To meet the demand for higher data rates, the present invention provides a system utilizing telecommunication data encoding methodologies in conjunction with a load bearing data cable having enhanced bandwidth to increase transmission data rate.

This invention also provides a method of well logging data transmission having a higher data rate.

SUMMARY OF THE INVENTION

In general, the present invention provides a logging data transmission method and apparatus. The apparatus includes a logging cable having improved bandwidth characteristics.

In one embodiment, a logging cable has a twisted pair of signal conductors, each of the conductors being separately insulated. An insulation sheath surrounds the twisted pair of conductors, and a tensile load sheath surrounding the insulation sheath, the tensile load sheath comprising a plurality of filaments provides the support necessary for downhole applications.

In an alternate embodiment, a cable is provided having at least 6 twisted pairs of conductors disposed around a center conductor, all conductors being within the insulation sheath. This configuration may have twisted pair conductors operating in a single conductor mode or in differential mode.

A system having an improved data transmission rate is provided comprising a downhole well data sensor and a downhole data transmitter such as a modem and an encoding method of QAM, CAP or DMT. Included in the system is a surface data receiver complementary to the downhole transmitter. A data transmission cable linking the transmitter and the receiver, the cable having at least one pair of insulated conductors wound in a substantially helical twist, an insulation sheath surrounding the twisted pair of conductors and a tensile load carrier surrounding the

insulation sheath, the load carrier comprising a sheath of tensile load carrying filaments.

Also provided is a method of transmitting data from a well borehole to a surface location comprising transmitting the signal with a downhole data transmitter and conveying the signal on a data transmission cable linking the transmitter and to a surface receiver, the cable having at least one pair of insulated conductors wound in a substantially helical twist, an insulation sheath surrounding the twisted pair of conductors and a tensile load carrier surrounding the insulation sheath, the load carrier comprising a sheath of tensile load carrying filaments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross section view of a cable according to the present invention.

Figure 2A is a simulation showing attenuation as a function of frequency using the dimensional and material specifications of a cable according to the present invention as a starting point for the simulation.

Figure 2B is a simulation showing attenuation as a function of frequency for a cable in accordance with the present invention using measured values of capacitance as the simulation input.

Figure 2C is a simulation showing attenuation as a function of frequency using correction factors due to the effects of armor surrounding the conductors of a cable according to the present invention.

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Figure 3 is a cross section view of a 7-conductor cable configuration according to the present invention.

Figure 4 is a schematic representation of a wireline system according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a cross section view of a cable according to the present invention. A cable **100** includes a twisted pair of insulated conductors **102** and **104** helically twisted together and about a central axis of the cable. Each of the insulated conductors **102** and **104** comprises a group of electrically conductive stranded wires **106** encased by a tightly fitted, tubular sheath of insulating material **108**. The stranded wires may be

copper or any other suitable metallic material, and the insulating material **108** is preferably an extrudable plastic, which maximizes electrical insulation and temperature characteristics while minimizing the insulation thickness and dielectric constant. For downhole applications, a preferred insulating material **108** is a fluorinated ethylene propylene (FEP) plastic such as Teflon®. It may also be a combination such as Teflon®/Tefzel®, both of which are well known insulators. If FEP insulation is used for a downhole data transmission application, a thickness of 0.0125" (.32mm) is recommended. Power applications may require more insulation. A protective elastomer bedding **110** is disposed around the twisted pair to provide protection from abrasions and other damage due to rough handling and harsh environments.

The cable **100** includes a tensile load bearing tubing **112** comprising an inner layer **114** and an outer layer **116** of wires. The inner layer of wires **114** is a plurality of stranded structural steel wires with 0.025" (.64 mm) total outer diameter helically wound around the elastomer bedding **110**. The outer layer **116** is a plurality of stranded structural steel wires with 0.0345" (.88 mm) total outer diameter helically wound around the inner layer **114**.

The overall outer diameter of a cable built to these dimensions would be 0.025" (6.35 mm). The relationship between resistance and diameter of a conductor is inversely proportional and the load bearing capability is directly proportional to the diameter. These relationships would normally lead one to larger cable designs. However, the overall diameter of a cable should be minimized in a downhole application, because the pressure of the fluid in the well may force a cable out of the well if the diameter is too large.

Referring now to **Figure 1** and **Figures 2A through 2C** showing bandwidth plots based a twisted pair load bearing cable as described above and shown in **Figure 1**. **Figure 2A** is a simulation using dimensional and material specifications of a cable as a starting point for the simulation. **Figure 2B** is the same simulation using values from measurements with a capacitance meter. **Figure 2C** is a simulation using correction factors due to the effects of armor **112** surrounding the conductors **102** and **104**.

The most useful capacitance to know is the effective capacitance per foot (C_{eff}) of the cable. This is the effective capacitance between the conductors **102** and **104**. To determine C_{eff}, equations are used that require measured values between the conductors **102** and **104** (designated

as C_{12m}) and between each conductor and the armor **112** (designated as C_{13m} and C_{23m} respectively.) The computation is initiated with an experienced based empirical value of 1 F for the same parameters, C_{12}, C_{13} and C_{23}. To determine the actual C_{12} or C_{eff}, equations are then set up as follows:

$$\frac{C_{13} \times C_{23}}{C_{13} + C_{23}} + C_{12} = C_{12m};$$

$$\frac{C_{13} \times C_{12}}{C_{13} + C_{12}} + C_{13} = C_{13m}; \text{ and}$$

$$\frac{C_{23} \times C_{12}}{C_{23} + C_{12}} + C_{23} = C_{23m}.$$

The equations are then iteratively solved for the correct values of C_{12}, C_{13}, and C_{23} yielding:

C_{12} = 2.999 x 10-11 F/m;

C_{13} = 8.999 x 10-11 F/m; and

C_{23} = 8.999 x 10-11 F/m.

Therefore, since 1m = 3.28084 ft, the C_{eff} of C_{12} for the cable described is actually 9.144 pF/ft. Compare this to the typical cable values of 40-60 pF/ft as stated above. The capacitance and conductor

configuration of a cable according to the present invention results in a bandwidth of about 350 KHz.

There are two modes of operation or configuration modes useful for the twisted pair cable described above. These are the single conductor mode and the twisted pair or differential mode. In the single conductor mode, the ends of the conductors **102** and **104** are tied together electrically. A signal transmitted on the cable is then sensed with reference made to the armor **112**. In the differential mode, the conductors **102** and **104** are each used independently for signal transmission, and the signal is sensed as a differential between the conductors **102** and **104**. The bandwidth of either configuration is larger than the bandwidth of current single conductor load bearing cables used in well logging systems.

Figure 3 is a cross section view of a 7-conductor cable configuration **300** according to the present invention. In this configuration, a core or center conductor **302** is covered in an insulation material **304** such as the extrudable Teflon or Teflon/Tefzel combination as described above. Six twisted pair wires **306,** each comprising twisted pair insulated conductors **308** and **310** as described above with respect to **Figure 1,** are disposed around a circumference of the center conductor **302**. The twisted pairs are also insulated as described in **Figure 1** with a protective cover **312**. The

center **302** and surrounding twisted pair conductors **306** are encased in an insulating dielectric material **314**, several of such materials being well known in the art. Also well known in the art and not shown separately here is a plurality of fiber cords running axially the length of the cable and disposed in the dielectric material **314**. These cords provide internal strength and stability to the cable to ensure the conductors are substantially fixed with respect to the internal distance between each other. Disposed circumferentially around the dielectric material **314** is an elongated tubular sheath **316**, which may be a conductive paste, a plastic tape or an insulation material like well known in the art. A tensile load bearing covering comprised of an inner layer of wires **318** and an outer layer of wires **320** is disposed about the sheath **316**. The inner layer of wires **318** is a plurality of stranded wires with helically wound around the sheath **316**. The outer layer **320** is a plurality of stranded wires helically wound around the inner layer **318**.

Sub A3 In this configuration, center conductor **302** is shown as a single conductor. However, the intent is not to exclude the use of a twisted pair for the center conductor. Also, the preferable mode for the twisted pair wires is the single conductor mode where the ends are electrically connected, but the differential mode may be preferable in a particular

application. As known in the art, any conductor may carry both data and power simultaneously.

Figure 4 is a schematic representation of a wireline system **400** according to the present invention. A tool **402** disposed in a well borehole **404** includes one or more sensors **406** for measuring parameters such as pressure, temperature, flow rate, etc.. A processor **408** is located within the tool **402** for processing and encoding data received from the sensor **406**. The processor **408** is connected to a downhole modem **410**. The modem **410** can be of any high data rate type used in two-conductor communication using an encoding method such as quadrature amplitude modulation (QAM), carrierless amplitude and phase (CAP) modulation, or discrete multi-tones (DMT) modulation. The tool **402** is supported by a load bearing communication cable **412** as described above in **Figure 1** or **Figure 3** depending on the application needs.

At the surface the cable is carried by a sheave and winch assembly **414**, and the end of the cable **412** is connected to a surface control unit **416** comprising a surface modem **418**, a processor **420**, an output/storage device **422**. The surface modem is complementary to the downhole modem **410**, and the processor **420** is connected to the surface modem **418** to receive, decode and process the data transmitted to the surface.

The processor **420** is also used to send commands to the instruments downhole via the modem-cable-modem connection. An output device/storage **422** such as a display screen, printer, magnetic tape, CD, or the like is connected to the processor for display and/or storage of the processed data. The output device **422** may also include a transmitter **424** for relaying the processed data to a remote location.

In operation, a well engineer or user deploys the tool **402** supported by the cable **412** in the well **404** to a desired depth using the winch and sheave mechanism **414**. Commands generated by user input, algorithm, or a combination are encoded at the surface using one of the methods described above. The encoded commands are then transmitted by the modem **418** through the cable **412** to the tool **402** disposed in the well. The downhole modem **410** receives the command which is then decoded for downhole operation of the tool.

When sensors **406** are activated to sense a desired parameter, the sensed parameter is delivered to the downhole processor **408** for pre-processing or sent directly to the surface. In either case, the data is encoded using one of the methods described above and transmitted by the downhole modem **410** through the cable **412** to the surface control unit **416**. At the surface, the surface modem **418** receives the data. The

processor **420** decodes the signal, performs further processing of the data, and the data is then displayed on a screen, printed on a printer, stored on magnetic tape, CD, or the like. The data may also be relayed to any remote location using a transmitter **424**.

The foregoing description is directed to particular embodiments of the present invention for the purpose of illustration and explanation. It will be apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible without departing from the scope and the spirit of the invention. It is intended that the following claims be interpreted to embrace all such modifications and changes.